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Research article

Understanding the relationships between water quality, recreational fishing practices, and human health in Phoenix, Arizona

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A B S T R A C T

Across the United States, recreational freshwater fisheries are not only an important leisure activity, but can also provide a relatively inexpensive source of protein in local diets. However, recreational freshwater fisheries are generally not well-monitored in terms of fish consumption vs. catch and release, nor are all recreational surface waters regularly monitored for the presence of potentially harmful contaminants in water or fishes. In six urban lakes that support recreational fisheries in Phoenix, Arizona, a majority of surveyed anglers reported eating recreationally caught fishes, even though they thought the water might be polluted. Surface water samples collected from the six urban recreational fishery lakes showed varying levels of organic contaminants, including pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and phthalates. As many Phoenix urban recreational fisheries lakes and ponds are located in low income and high minority neighborhoods, the results of this pilot study could be used to inform urban fisheries management and other agencies of the potential need for fish consumption advisories, inform actions to improve water quality in urban lakes and ponds that support urban fisheries, and support further research and monitoring, in order to reduce potential risks to public health.

1. Introduction

Recreational fishing is a common hobby in the United States (U.S.), where approximately 33 million fishing licenses are issued each year, and is more popular than bowling or playing basketball, soccer, or softball (American Sportfishing Association, 2013). While some individuals only fish for recreational purposes, there are many who eat the fish that they catch, with some residents even obtaining their main source of protein from fishing at recreational lakes (Neff et al., 2014). However, across the U.S., recreational freshwater fisheries are generally not well-monitored in terms of fish consumption vs. catch and release, nor are they regularly monitored for the presence of certain contaminants, such as phthalates or pesticides (Naidu et al., 2016) Therefore, U.S. anglers, especially in urban areas, may be eating fish from potentially polluted waters, which could reduce the positive health benefits of fish consumption (Burger, 2000).

For surface water protection, states are required to enforce laws with maximum allowable contaminant levels that can be as strict or stricter than EPA recommended guidelines (EPA, 2016). However, not all contaminants are regulated in surface waters, often because they lack established recommended thresholds of concern or maximum allowable contaminant levels, and/or sufficient toxicological data on aquatic ecosystem impacts (EPA, 2016). As a result, many contaminants not included in regulatory monitoring programs, can be present but generally undetected in surface waters and associated aquatic organisms. In freshwater fisheries with known pollutants and carcinogens, fish advisories can be issued to protect human health. However, in many parts of the U.S. anglers were often found to continue eating fish from contaminated waters, indicating that advisories may fail to effectively communicate public health risks (Burger and Gochfeld, 2006). Thus, there is a significant gap in regulation and consideration of public health for recreational anglers who regularly eat fish from urban, and potentially other, freshwater fisheries. While a number of studies on recreational fish consumption, surface water pollutants, and

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environmental and public health risks have been conducted in the U.S. (Watanabe et al., 2003; Blocksom et al., 2010; Neff et al., 2014; among others), no studies have been identified on fish consumption rates and urban surface water contaminants in urban fisheries in Phoenix, Arizona. Therefore, the objectives of this study were to determine urban fishers' fish consumption patterns and perception of pollution in six urban lakes within the Arizona Game and Fish Department's Community Fishing Program, in comparison to actual levels of detected organic contaminants (e.g. pesticides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, phthalates, etc.). The results of this 4-month pilot study could help to improve Phoenix urban fishery management, inform urban surface water quality standards and regulations, and guide future research in water quality and urban fisheries in the region.

A number of studies throughout the U.S. have highlighted the need for improved water quality regulations and more effective fish advisories. For example, Watanabe et al. (2003) identified nine species of fish (blue catfish, carp, channel catfish, cobia, crayfish, flathead catfish, red drum, spotted gar and striped bass) and seven chemicals of concern (aldrin, dieldrin, alpha-benzene hexachloride, gamma-benzene hexachloride, heptachlor epoxide, arsenic, and mercury) in the lower Mississippi river, which could cause cancerous health risks from fish consumption. A similar study of Lake Erie found that some locally consumed fish species contained polychlorinated biphenyls (PCBs) and mercury, but that the overall benefit of eating these outweighed the health risks (Neff et al., 2014). However, in many cases, anglers are not aware of the contaminants present, and therefore do not possess the knowledge to make personal health decisions (Neff et al., 2014). In the upper Mississippi, Missouri, and Ohio rivers, Blocksom et al. (2010) found that PCBs, PBDEs, chlordane, dieldrin and DDT were present in all the rivers, with dieldrin and PCBs being the largest contributors to cancer risks in humans. PCBs, which are known carcinogens, have been documented in rivers around New York City, resulting in fish advisories. However, New York anglers reported high levels of fish consumption from these rivers despite advisories (Ramos and Crain 2001). Although the health impacts for many of the legacy contaminants have been investigated, the possible health implications from emerging contaminants in the environment, such as phthalates, pharmaceutical drugs, nanomaterials, and newer pesticides are largely unknown (Naidu et al., 2016). The scarcity in knowledge, lack of regulatory standards, and the identification of new contaminants and their risks to human health, should be addressed through greater research as well as governmental and community intervention (Naidu et al., 2016).

The Phoenix-metro area provides a large number of relatively small, artificial urban lakes, ponds, and canals for recreation. Water stocked in these urban ponds and lakes originate from a number of sources including canal water, treated wastewater, and groundwater. Groundwater and surface water from the Colorado, Salt, and Verde Rivers are the main sources of water for the canal system (Larson and Grimm, 2012). Most urban and recreational waters are monitored as surface waters of the U.S. by Arizona Department of Environmental Quality (ADEQ, 2011). The Arizona Game and Fish Department (AGFD) manages the Community Fishing Program and regularly stocks the lakes with inspected hatchery fish, provides fish advisory information, monitors the waters, and regulates fish licenses within their urban fishery program (AGFD, 2016). There are approximately 28 of these urban recreational lakes and ponds that are part of the program within the Phoenix-metro area with seven specifically located within the City of Phoenix.

As the sixth largest city in the U.S., the city of Phoenix supports an estimated 2015 population of over 1.5 million, while the Phoenix-Mesa-Scottsdale metropolitan area is home to 4.5 million people (US Census, 2016a). Water is a limiting resource in this Sonoran Desert ecosystem, which receives 20.4 cm of rainfall annually, and has an average maximum summer temperature of 40 °C and an average minimum winter temperature of 8 °C (NOAA, 2016). In the 20th century, city and tourism promoters sought to "do away with the desert" and promote Phoenix as an "oasis" through the use of groundwater, reservoir water, and long-distance transferred Colorado River water to irrigate grass and other non-native vegetation, and fill water features on private land and in public parks (Larson et al., 2009; Larson and Grimm, 2012). While the city of Phoenix, and the Phoenix metropolitan area, have been among the fastest growing population centers in the U.S. over the last twenty years, Phoenix continues to have a large amount of parkland: 19,932 hectares (ha), representing 15% of the city's total land area and amounting to 13 ha of land per 1000 residents. The U.S. median amount of city parkland per 1000 residents is 5 ha (TPL, 2016).

Phoenix city parks serve a population that is mostly white (46.5%) with a growing Hispanic/Latino population (40.8%) and smaller African American (6.5%), Asian (3.2%), and American Indian (2.2%) populations (US Census, 2016b). Phoenix was hit hard by the recent U.S. recession (2008–2009) and continues to recover. Median household income is $46,881 compared to $53,482 nationally, and an estimated 23.2% of city residents live below the poverty line (US Census, 2016b). Although Phoenix boasts some of the largest city parks in the US (e.g. South Mountain Park and Sonoran Preserve), accessibility to these parks can be problematic particularly for lower income residents without cars. Of the 75 largest cities in the U.S., Phoenix ranks 66th in walking access to parks, and only 45% of its residents are within 0.8 km of unobstructed walking distance from a publically-owned park (TPL, 2016). Environmental justice, defined as the disproportionate exposure of minority groups to environmental hazards such as pollutants and the access of these groups to environmental amenities like parks, has long been an issue in Phoenix (Ibes, 2015; Bolin et al., 2013).

2. Materials and methods

2.1. Survey and sampling sites

Six of the seven Phoenix urban fishing sites, all located within the city of Phoenix, were selected for the fisher survey and to conduct water contaminant analyses: Alvord Lake, Cortez Lake, Desert West Lake, Encanto Lake, Steele Indian School Lake, and Papago Ponds. The seventh site within the city of Phoenix (Roadrunner Lake) was not included as it has only recently been added to the AGFD Community Fishing Program. Lake size across all sites averages about 1–3 ha, with the exception of Alvord Lake, which is 10 ha, with maximum depths of approximately 3–5 m. However, vegetation and landscape design is similar throughout each park and recycling and waste cans are provided at all locations. Golf courses and adjacent canal systems are commonly found near most of the parks. The water bodies are regularly stocked (mostly in the non-summer months) with catfish, rainbow trout, bluegill, bass, carp and sunfish.

Based on demographic and other data available from the 2010 U.S. Census, and the American Community Survey 2009–2013 (MAG, 2016), many of the urban fishing sites are located in or near lower income and higher minority population areas. Table 1 shows the percentage minority population, median income, and percentage families below poverty level at the 6 sampling locations (MAG, 2016). It is important to note that some sites are located in a census block, where residents have higher incomes/lower minority populations, but are surrounded by adjacent lower income/higher minority census blocks.

2.2. Survey methods

The face-to-face survey was designed for a short 10 to 15-minute interview time, with ten main questions, most with short sub-questions, including both close-ended and open-ended questions. The survey instrument was tested before implementation, and was always administered by the same surveyor. The questions aimed to discover the distance anglers lived from the lakes, how many fish they caught, how many and how often they ate the fish they caught, how they prepared the fish for eating, who they shared their fish with, and their perceptions of environmental quality (see Supplemental Materials, S1). Each of the six sites was surveyed twice a week (Wednesdays and Saturdays) on two occasions from September to December 2015, for a total of four survey days per site over the 4-month study period. Surveys were consistently conducted in early mornings, from 7:00 a.m. to 9:00 a.m., and only individuals 18 years or older could participate. At each site, individuals observed fishing were randomly approached, asked if they would agree to participate in the survey, and then if yes, answers were recorded on paper. Information about the background and purpose of the survey was provided to each individual and their responses remained anonymous. Over the 4-month period a total of 64 respondents were interviewed; 9 at Alvord Lake, 14 at Cortez Lake, 16 at Desert West Lake, 7 at Encanto Lake, 9 at Steele Indian School Pond, and 9 at Papago Ponds. A specific number of respondents were not pre-determined for the study, as there is little information available regarding the total number of Phoenix urban recreational anglers. However, the surveyor attempted to survey all anglers present during the surveying/sampling period. Generally, most anglers present chose to participate. However, approximately 10–15 anglers who were approached chose not to participate in the survey, with English language being a barrier for 5 individuals who spoke only Spanish. The other 5–10 anglers who did not participate, indicated that it was because they were busy fishing or spending time with friends and family.

2.3. Water sampling and organic contaminant analyses

Water sampling consisted of collecting two 1-liter water samples from each site during each survey event (6 sites sampled 4 times each, yielded 48 water samples) in sterilized glass jars with PTFE-lined caps, which remained on ice or refrigerated until processed. Within 24–72 h after collection, each 1-liter water sample was pre-filtered with 47 mm glass fiber filters. Water samples were then extracted with solid-phase extraction C18 disks (Empore 3M, 47 mm) conditioned with acetone and hexane. The C18 disks were eluted with acetone and hexane, dried with sodium sulfate, and concentrated to a volume of approximately 1 ml. Concentrated sample extracts were passed through a second, smaller sodium sulfate column with hexane, and then concentrated to a final volume of 0.5 ml with nitrogen gas. All samples were initially spiked with p-terphenyl as a recovery surrogate, with final extracts spiked with tetracosane d-50 as an internal standard. All surface water samples, including field and laboratory blanks, were analyzed for organic contaminants using a Varian 3800 gas chromatograph in tandem with a Saturn 2200 electron ionization mass spectrometer. For quality control/quality assurance, two trip blanks (bottles filled with tap water on-site) and two laboratory blanks (tap water analyzed in the lab) were also analyzed every month. A complete list of potential contaminants searched for, with minimum detection limits, is presented in Supplemental Materials S2. Minimum detection limits (MDL) were estimated by doubling the lowest standard concentration that showed a peak, with a signal-to-noise ratio greater than 3. Total concentrations of detected contaminants were summed according to class (e.g. pesticides, PCBs, phthalates) for presentation. Potential contaminant concentrations in fish were calculated based on each chemical's K_{ow} value and the maximum water concentration for that chemical measured at the site, during the study period. Fish contaminant concentration (in μg/g wet weight) was calculated using the formula $\log BCF = \log 0.85K_{ow} - 0.70$, where BCF = estimated concentration in fish divided by the maximum concentration in the water (Schwarzenbach et al., 2004).

3. Results

Angler interviews, or surveys, were primarily conducted to determine the anglers' fish consumption patterns and perception of pollution across six urban lakes within the Arizona Game and Fish Department's Community Fishing Program. In order to compare angler perception of water quality and estimate potential fish consumption risk, levels of detected organic contaminants (e.g. pesticides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, phthalates, etc.) were also quantified from water samples collected during each surveying event.

3.1. Survey results

Although the original survey contained 10 questions with sub-questions (Supplemental Online Material), results were summarized by subject as responses to some questions or sub-questions were sometimes redundant (e.g. how often they fished per week vs. per year), depending upon the level of detail provided by the respondent. In order to better understand potential socioeconomic and/or environmental justice impacts, at least one set of questions were designed to determine if anglers were fishing in or near their own neighborhoods. Results indicated that most people lived relatively close to the parks that they fished at, with an average driving time by car of less than 15 min in four of the sites, and an average driving time of less than 20 min in the other two sites (Fig. 1). It was hypothesized that anglers drove from farther distances to fish at Alvord Lake because it is one of the largest sites, and to Papago Ponds because they are a popular and historic location.

Table 1
Demographic information for urban fishing site census blocks.

Urban Lake Name	Address	Percentage (%) Minority Population	Median Income (U.S. Dollars)	Percentage (%) Families Below Poverty Level
Alvord Lake	7858 S 35th Ave., Phoenix, AZ 85339	55–79	37,281–58,167	18–33
Cortez Lake	3434 W Dunlap Ave., Phoenix, AZ 85051	36–55	2499–37,281	18–33
Desert West Lake	6602 W Encanto Blvd., Phoenix, AZ 85035	79–100	37,281–58,167	18–33
Encanto Lake	2605 N 15th Ave., Phoenix, AZ 85007	19–36	58,167–83,646	0–7
Steele Indian School Pond	300 E Indian School Rd., Phoenix, AZ 85012	19–36	37,281–58,167	0–7
Papago Ponds	625 N Galvin Parkway, Phoenix, AZ 85008	7–18	37,281–58,167	7–18

The majority (84%, N = 54) of anglers reported fishing during the stocking season or all year, with 65% reporting that they fished at least once a week. In Phoenix, the stocking season is primarily from September through May, and the off season occurs during the very hot summer months. Given the very hot summers in Phoenix, only a few anglers reported fishing during the off season or inconsistently throughout the year. The majority (58%, N = 37) surveyed ate or would like to eat fish from the ponds. Of those that reported eating the fish they caught, the average reported amounts of individual fishes caught (and consumed) were approximately 0.75 fish per week (±1.6), 2.6 fish per month (±5.5) and 15 fish per year (±24.3). Reasons that anglers that did not report eating the fish they caught were: they only fish for recreation (12 responses), they do not like the taste of fish (5 responses), they believe that the water quality is poor (4 responses), they give away their fish to others (4 responses), they have not caught fish yet (2 responses), or they are not from the Phoenix area (1 response). However, many anglers commented that there may be other underlying reasons why other people (not necessarily themselves) don't eat fish, such as water/fish quality perceptions, laziness to prepare the fish for eating, and ethical reasons for not killing fish.

Approximately 84% of anglers that ate the fish they catch also shared it with friends, neighbors or family members, while only 16% ate it by themselves. The most common type of fish consumed by anglers was catfish, followed by trout (Fig. 2). The average numbers of fishes reportedly shared with friends, neighbors and family were similar to those reportedly consumed by anglers, and were approximately 0.3 fish per week (±0.83), 1.7 fishes per month (±2.4), and 17 fishes per year (±19.7). In terms of preparation, all respondents reporting they ate the fish they caught either gutted or filleted the fish, depending on the type of fish that was eaten. Frying was the most common cooking method followed by baking and grilling.

Anglers were asked to rank water and fish quality on a scale from 1 (dirty) to 5 (clean), with responses separated into three categories: 1–2 = dirty, 3 = medium, and 4–5 = clean. Across all sites, respondents consistently ranked water quality as lower than fish quality, with the largest differences seen in Cortez Lake, Desert West Lake and Papago Ponds (Fig. 3). Surprisingly, a higher proportion (30%, N = 11) of individuals that reported eating the fish ranked the water "dirty" compared to those who do not eat the fish (22%, N = 6). Similarly, a few individuals (8%, N = 3) that reported eating the fish also ranked the fish "dirty," while only 1 respondent who did not eat the fish ranked fish as "dirty." However, across all respondents, whether they ate the fish or not, more than 50% (33 out of 64 respondents) ranked water quality differently than they ranked fish quality (Table 2).

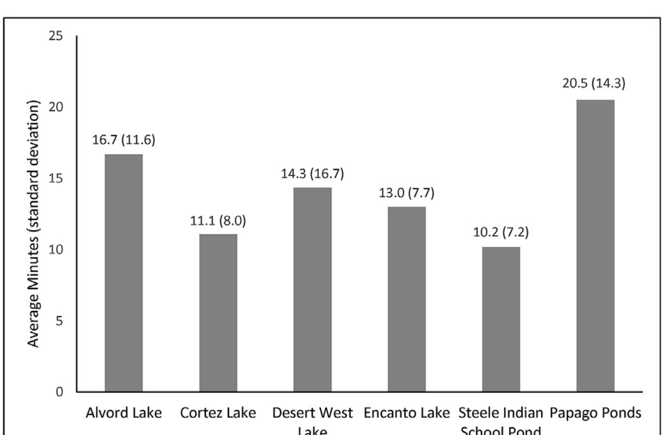

Fig. 1. Average time (minutes, standard deviations) reported by anglers to drive by car for each surveyed Phoenix urban lake.

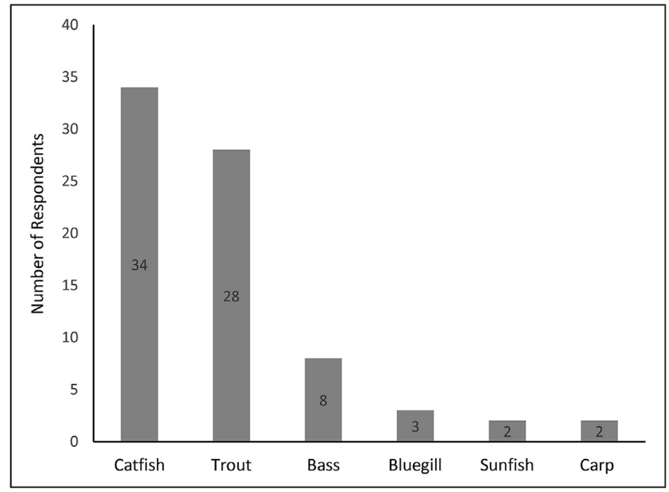

Fig. 2. Number of respondents reporting to eat different fish species caught in Phoenix urban lakes.

3.2. Water quality sample results

The highest number of detected organic contaminants (15) and highest combined concentrations were found at Steele Indian School Pond, compared with fewer numbers of contaminants at Papago Ponds (12), Alvord Lake (11), Desert West Lake (10), Cortez Lake (8), and Encanto Lake (7) (Fig. 4). The most commonly detected contaminants were phthalates, likely from plastic debris and plastic degradation. A number of pesticides were also detected across sites, including several organophosphate insecticides (diazinon, malathion, fenitrothion, and ethion), some legacy and current use organochlorine insecticides (aldrin, trans-nonaclor from chlordane, DDT) and the herbicide propham. Three PCB congeners (PCB 52, PCB 14, and PCB 49) were detected only at Steele Indian School Pond. Flourene, a polyaromatic hydrocarbon, was also detected at 4 sites. Calculation of selected contaminants for estimated fish body burdens (in μg/g wet weight) based on equilibrium conditions showed potentially high concentrations of butylated hydroxytoluene (BHT), Aldrin, PCB 52, and two phthalates, diethylhexyl phthalate (DEHP) and di-n-octyl phthalate (DNOP), across sampled sites (Fig. 5). Of these chemicals, only 3 have EPA established minimal risk levels, or established chronic toxicity thresholds below which there is not expected to be adverse effects (Agency for Toxic Substances and Disease Registry, 2016). These include Aldrin (<0.03 μg/kg/day), PCBs (<0.02 μg/kg/day), and DNOP (<400 μg/kg/day). For an average 50 kg person consuming 200 grams (7 ounces) of fish per day, and based on the highest calculated fish tissue concentrations shown in Fig. 5, these chronic toxicity thresholds are exceeded for Aldrin (~7 μg/kg/day) and PCBs (~5 μg/kg/day), but not for DNOP (~230 μg/kg/day).

4. Discussion

The results of this pilot study showed that the majority (58%) of anglers fishing at the six surveyed urban recreational fishing sites are eating the fish they catch, and are also sharing their catch with friends, neighbors and family. Results also show a disconnect between perceptions of water quality and fish quality, as at least half of all respondents ranked water differently than fish, and of these

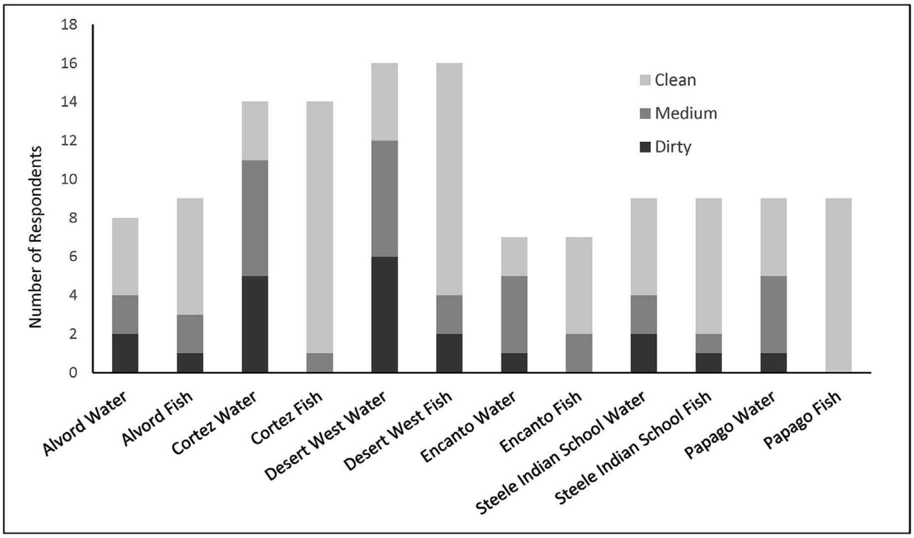

Fig. 3. Angler perceptions (number of respondents) of water and fish quality at each site, ranked from dirty to clean.

Table 2
Misconceptions between water and fish quality relationships.

Water and Fish Quality Ranking	Number of Responses
Water = clean, Fish = medium	1
Water = dirty, Fish = clean	11
Water = medium, Fish = clean	19
Water = dirty, Fish = medium	2
Total	**33**

almost all ranked the fish as "cleaner" than the water. A number of organic contaminants were detected across all of the sampled urban fishing sites, including pesticides, PCBs and phthalates. Although the average number of fish eaten per week by anglers reporting to eat the fish they catch is one or fewer fish, based on calculated contaminant body burdens from water quality results, consumption of just 200 grams (7 ounces) of a given fish in one day by a 50 kg person may exceed established chronic risk levels for Aldrin and PCBs.

4.1. Public health concerns

As the majority of anglers regularly fish from the lakes throughout all or most of the year, there is a high likelihood that at least some of the contaminants detected are being consumed regularly. Although exact body weights of anglers and amounts of fish consumed at one sitting were not explored, regular consumption of recreationally caught fish across all sites may exceed chronic toxicity thresholds for exposure to Aldrin, which was detected at all sites, and in the Steele Indian School site, of PCBs. The organochloride insecticide Aldrin was discontinued in 1970, but reintroduced during 1972–1987, and is very persistent in the

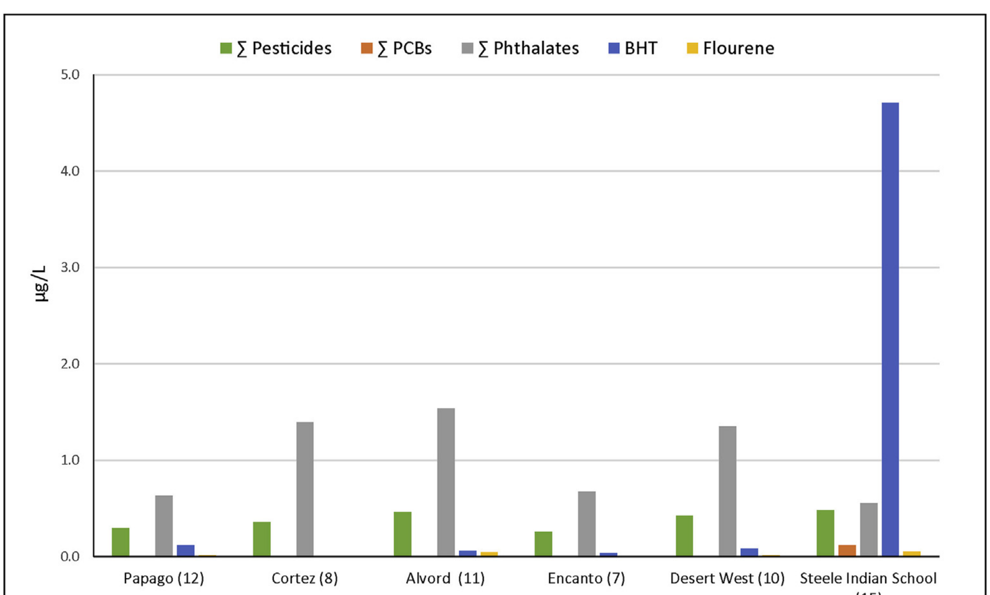

Fig. 4. Maximum summed concentrations (µg/L) in 1 liter of water for each contaminant class measured at each site. Number of total contaminants detected across all classes in parenthesis after site name.

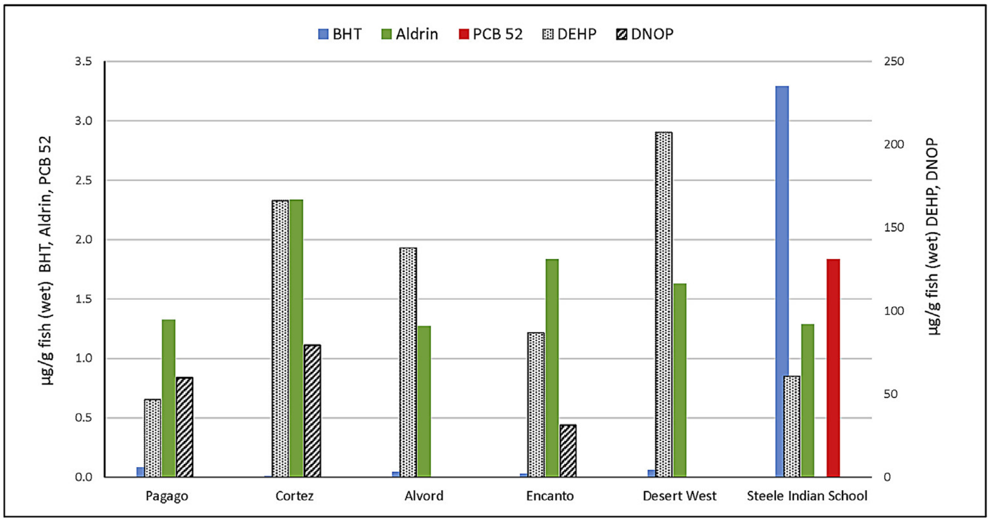

Fig. 5. Calculation of potential pollutant concentration in fish (μg/g wet weight) based on maximum detected water concentrations of selected pollutants, K_{ow} and BCF.

environment. When consumed, Aldrin generally converts to Dieldrin, with fish having some of the highest bioaccumulation rates for Dieldrin (Jorgenson, 2001). Acute human symptoms of Aldrin (or Dieldrin) exposure include nervous system failure, convulsions, and liver damage. Small to moderate dosages over a long time are known to cause symptoms such as irritability, vomiting, dizziness, headaches, and uncontrollable muscle movements, and are listed as probable human carcinogens, according to the Agency for Toxic Substances and Disease Registry (2002).

PCBs and BHT were only detected at the Steele Indian School pond. PCBs were mainly used commercially/industrially as coolant and dielectric fluids for electronics up until the 1970s, when they were banned in the U.S. because many PCBs were discovered to be likely carcinogens (Agency for Toxic Substances and Disease Registry, 2000). Acute PCB toxicity in humans has not been observed. However, chronic exposure can cause adverse gastrointestinal, respiratory effects and liver effects, as well as harm to skin and eyes. Some studies showed possible developmental issues in children born to pregnant women exposed to PCBs. Long-term PCB exposure may cause low fertility in men. Although banned, many PCBs remain in the environment because they do not break down easily and bioaccumulate and biomagnify in aquatic species, posing potentially serious risks to recreational anglers who fish from PCB contaminated lakes (EPA, 2000). BHT is used in petroleum products, food, packaging, cosmetics, and animal feed and there are few to no known adverse effects in humans (National Toxicology Program, 2014).

Di-(2-ethylhexyl) phthalate (DEHP) and di-n-octyl phthalate (DNOP), derived from plastics, were detected in all sampled water bodies, but calculated concentrations in fish tissues did not exceed available minimum risk levels. Environmental accumulation is not prominent in phthalates and generally remains below harmful levels, however, human exposure to multiple types of phthalates and at larger loads than metabolic removal is not well studied (Mankidy et al., 2013). Higher body burdens of various phthalates, beyond consumption in recreationally caught fish, can also occur from consumption and exposure to other sources of plastics and microplastics including food packaging, personal care items, and more (Mankidy et al., 2013). While not acutely toxic, animal studies on phthalates suggest that long term exposure can cause harmful effects in the endocrine system. Additionally, DNOP has been found to induce liver, immune system, and kidney problems in animals, according to the U.S. Consumer Product Safety Commission (2010). Pre-natal exposure to DEHP can disrupt the development of reproductive function in young men (Axelsson et al., 2015).

Although no minimum risk levels are available, only trace amounts of fluorene, a PAH, were detected. When products such as wood, garbage, oil, gas, coal, etc. are not completely burned, a number of different PAHs are formed. PAHs occur naturally and anthropogenically in products such as plastics, pesticides, dyes, asphalt, tar, and coal. Microorganisms in the environment generally break down PAHs within weeks or months. Some types of PAH can cause cancer in animals, indicating possible adverse health effects in humans. However, fluorene has not yet been observed to harm humans (Agency for Toxic Substances and Disease Registry, 1995).

As most individuals that reported eating the fish they catch also share it with friends or family members, chronic health concerns may impact not just the anglers but also other members of their communities, including pregnant women and children, who may be at higher risk and have lower thresholds of chronic toxicity. Additionally, the commonly eaten fish is catfish, which can accumulate pollutants more than other species given its relatively longer life and benthic habitat, causing worse health impacts if consumed (EPA, 2014). All individuals responded that they either gutted or filleted the fish, which can reduce the amount of consumed pollutants by excluding those that accumulate in organs. However, most (21) people fried the fish, which seals more pollutants into the fish compared to other methods of cooking (EPA, 2014). Four people boiled the fish, which is another practice that traps pollutants into the fish, especially if it is consumed with the broth. The EPA recommends that fish be baked, grilled, or broiled to reduce pollutant loads (EPA, 2014). Fortunately, these techniques were used by 14 individuals that cooked their fish, either as a supplement or an alternative to other cooking methods (frying, barbeque, boil, etc.).

4.2. Water and fish quality perceptions

The results of this pilot study showed a clear disconnect between perceived water quality and fish quality, which explains why anglers continue eating the fish they catch even if they believe that the water is dirty or of poor quality. While surveying, some anglers explained that they thought the fish were clean because fish came from hatcheries, even if they thought the water was dirty. Many residents fish from the lakes a day or two after they believe the lakes are stocked, and assume that the fish did not have time to accumulate pollutants. However, the amount and rate of pollutant partitioning into fish from the water column varies, depending on the type and concentration of pollutants in the water, as well as abiotic environmental conditions such as temperature, pH, etc. Some contaminants, such as heavy metals, can take days to months to accumulate in fish, whereas some organic pollutants only take a few minutes (Crosby, 1998). Burger et al. (1998) documented similar reasoning from anglers along an East Coast Estuary, stating that "many people expressed the view that the fish they caught were safer because they were fresher, and they responded thus even to questions about contaminants."

Concentrations of contaminants in fish and in the water column cannot be visibly detected. Pristine-looking lakes/fish can be quite polluted, while poorly-looking lakes/fish could be cleaner, which may contribute to why many Phoenix anglers have misconceptions about the relationship between land, water, and fish quality based on observation. As a result, fish advisories alone are often not sufficiently convincing evidence to stop fish consumption (Burger et al., 1998, 1999). In some cases, sensory experiences may have a stronger effect on consumption behaviors. For example, a significant percentage of anglers along the East Coast Estuary and in urban New Jersey reported that if fish smelled or tasted bad, or they saw or heard about someone getting sick from the fish, it convinced them to not eat the fish (Burger et al., 1998). Overall, there appears to be a lack of understanding about the relationship between water quality and contaminants potentially found in fish, which can influence individual perception of risk and subsequent decisions on fish consumption, especially as information about advisories and basic ecosystem knowledge can be confusing, are often not well-tailored to local angling communities, and/or not easily accessible (Burger, 2000).

4.3. *Environmental justice*

Most anglers reported that they live about 10 min or less by car from the park where they fish, and these areas have a high percentage of minority and low income households. Proximity to parks is an important environmental justice metric because parks can provide a host of ecosystem services to users, including recreational services and benefits to the neighborhoods adjacent to the parks, such as cooling and amelioration of the urban heat island effect (Rigolon, 2016; Boone et al., 2009; Ibes, 2015; Chow et al., 2011; Declet-Barreto et al., 2013). A number of studies across the U.S. (e.g. James River, VA, the Florida Everglades, the Savannah River, GA, and the Great Lakes, NY) have found that anglers from minority groups were more likely to eat fish from waters with fish advisories and also to eat larger portions than Caucasians (Harris and Jones, 2008; Fleming et al., 1995; Burger et al., 2001; Beehler et al., 2001). This was attributed to a lack of knowledge about the relationship between water quality and fish quality; adherence to cultural and traditional knowledge practices that may not be relevant or advisable in present contexts; limited access to fish advisory information; and problems with interpreting fish advisories.

The environmental justice literature on parks has moved beyond a simple consideration of minority population proximity to parks as a measure of environmental justice to an analysis of "who gets what and why," which has revealed the dis-amenities and risks associated with some urban parks located in or near minority neighborhoods (Boone et al., 2009; Ibes, 2015; Hughey et al., 2016). In metro-Phoenix, for example, anglers have access to fishing, a presumed amenity, but the water quality in the fishing lakes exposes them to a host of pollutants, some of which have documented health effects, if they eat the fish they catch. As recreationally-caught fish were found to be a source of quality protein for some anglers' households, this suggests that economic status (e.g. limited funds to buy food) in concert with minority status may play a role in vulnerability and exposure to pollutants, which are findings supported by other environmental justice research in the Phoenix area (Bolin et al., 2013). More refined methods of environmental risk assessment are increasingly available to better capture pollutant impacts to environmental justice populations. These include methods to incorporate differential doses and responses across various vulnerable populations (Schwartz et al., 2011), improved pollutant-fate and transport models and geostatistical analyses (Chakraborty et al., 2011), as well as cumulative risk assessments that include nonchemical stressors such as poverty and discrimination in the assessment paradigm (Sexton and Linder, 2011).

5. Conclusions

Given the relatively small sample size and short time-frame of this study, it should serve as a pilot to identify areas for further research and improved aquatic resource management. An ecosystem approach, that balances diverse societal objectives with abiotic and biotic knowledge and uncertainties about the ecosystem, has been proposed as a decision-making guide in the protection of recreational fishing waters (Hickley, 2009). This approach takes into consideration systemic gender and social inequities, recognizes various perspectives, encourages transdisciplinary research and collaboration, and acknowledges that "health is contingent on biophysical/social, economic and political environments." Such approaches have been successfully applied to various forms of fish consumption across aboriginal, fisher and urban communities from the Amazon to the Great Lakes (Webb et al., 2010). Because the ecosystem approach tackles multifaceted issues, it could be useful for managing urban recreational fishing challenges such as missing or ineffective fish advisories, gaps in regulatory monitoring, complex interagency management initiatives, and nonpoint source pollution control.

Given the relatively high Aldrin concentrations detected across all surveyed sites, and PCB concentrations in Steele Indian School pond, further research is needed to determine if fish advisories are warranted in some of the metro-Phoenix recreational fishing sites. If so, there needs to be effective collaboration between government entities to convey clear site-specific and fish-specific advisory information, and impactful design of risk communication tools, such as visual graphics (Burger and Gochfeld, 2006). Since minorities are generally at greater risk for contaminated fish consumption, community-based participatory research can be a successful strategy for creating effective fish advisories, engaging stakeholders, and ensuring public health and safety (Forget and Lebel, 2001). Additionally, given the gap in advisories and regulations between local, state, and federal government, both intrastate and interstate communication for recreational fisheries may be needed to harmonize regulations and advisories (Love et al., 2013).

As there are extensive data gaps on the effects of chronic exposure of a variety of known contaminants on humans and aquatic ecosystems, it is difficult to directly correlate pollutant water concentrations to actual health impacts. More research is needed on the actual concentrations of organic contaminants in fish being consumed, along with the potential aquatic ecosystem and human health impacts, especially for more vulnerable populations including pregnant women and children. To better refine estimates of potential human health risks, it would be advantageous to know the average fish portion consumed, the duration of time (months, years, etc.) anglers and family members spend consuming fish from a specific location, the method of fish storage (frozen or fresh), along with improved information on fisher and community demographics. Consequently, there is a need for improved and tailored community education programs, so that anglers can better understand the relationships between water, fish quality, and public health. Greater knowledge of these relationships will allow individuals to make more educated choices about their food and health. Lastly, inclusion of a Spanish speaking surveyor would allow for additional anglers and residents to be interviewed.

In sum, public health risks due to polluted recreational fishing waters do not just affect the Phoenix area. It is an issue that can be found across the U.S., due to ineffective fish advisories, gaps in water monitoring and contaminant toxicity data, complex governmental interagency cooperation, and variation in local, state or federal regulations. Minority and low-income areas are especially vulnerable to consuming contaminated fish and should be considered in decision making through an integrated, ecosystem approach.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2017.05.046.

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